

Review

Which Building Services Are Considered to Have Impact on Climate Change?

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Abstract: The building sector, as a major energy consumer with high direct and indirect CO₂ emissions, plays a vital role in the fight against climate change. In order to make buildings more comfortable, functional, efficient and safe, building services are used. Therefore, building services are the key to decrease their contribution to climate change. Due to the lack of organized literature on this topic, this paper presents the first comprehensive assessment of trends in the literature on building services related to climate change, which was completed by conducting a bibliometric analysis of the existing literature on the topic. The ultimate goal is to provide a source where researchers and other interested parties can find this information in an organized manner. Results show that the most abundant and recent studies related to building services are based on improving energy efficiency by optimizing systems such as ventilation or lighting, the latter with the installation of LED lights. In addition, recent studies have focused on social factors such as housing and urban growth.

Keywords: building services; climate change; literature trends; bibliometric analysis



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1. Introduction

Buildings have been identified as high energy consumers, as buildings and the building construction sectors account for more than 30% of the global final energy consumption and 40% of the total CO₂ emissions, both direct and indirect [1]. However, at the same time, heating and cooling of buildings is one of the areas where there is a high potential to decrease energy consumption and CO₂ emissions [2]. Heating and cooling are indeed clearly identified as energy-consuming building services. Nevertheless, building services other than these and other building energy services (e.g., lighting) should also be considered in order to have a holistic view of the real climate change mitigation potential of buildings.

Building services are the systems installed in buildings to make them more comfortable, functional, efficient, and safe [3]. Building services might include building control systems, energy distribution, and energy supply. This traditional description includes a classification of building services such as building management systems; energy generation, distribution and supply; escalators and lifts; facade engineering; fire safety, detection and protection; heating, air conditioning and air conditioning systems (HVAC); ICT networks; lighting; lighting protection; refrigeration; security and alarm systems; and water, drainage and plumbing.

Another definition states that building services aim at achieving a safe and comfortable indoor environment whilst minimizing the environmental impact of a building [4]. Then, other concepts appear in the framework of building services, with wellbeing, circular economy, and climate change mitigation becoming increasingly important, such as air quality, thermal comfort, and acoustic comfort. However, a more holistic approach would also include terms such as shelter, cooking, materials, embodied energy and embodied carbon, CO₂ emissions, GHG emissions, and pollution. Therefore, a potential classification of such building services could be the one presented in Figure 1. As it can be seen, building services have been classified into four types; safety-related services, comfort-related, services related to efficiency, and finally, services related to climate change. Within

each type, different building services are included, among them are those known as building energy services [5] (i.e., thermal comfort, lighting, energy generation, building management systems).



Figure 1. Identified building services.

However, when assessing the literature to evaluate building services and their relation with climate change, the literature is scarce and very dispersed. Therefore, the aim of this paper is to fill this knowledge gap by performing a bibliometric analysis of the existing literature on the topic. In more detail, this paper includes a comprehensive assessment of trends of the literature on building services related to climate change to give a source where researchers and other interested stakeholders can find this information in an organized manner.

2. Methodology

Bibliometrics allows to perform a wide statistical literature analysis of the existing publications in a determined research field [6]. Figure 2 presents the specific methodology utilized to define all the steps to map the state-of-the-art of the scientific topic researched within the scope of this paper. The first step consists of the definition of the research topic, from which two queries were developed, including the key messages of the paper. The next step was the selection of the proper database. On this matter, Wuni et al. [7] stated that the WoS and Scopus databases can be used to extract bibliometric data, but the content of both for the same research tends to differ. Moreover, Cabeza et al. [8] showed that Scopus contains more publications in the area of technology. Therefore, Scopus was selected as the database for the presented study. Then all references were downloaded, as well as the statistics for the bibliometric analysis. Finally, the software VOSviewer [8–10] was used to analyze relations between countries and keywords.

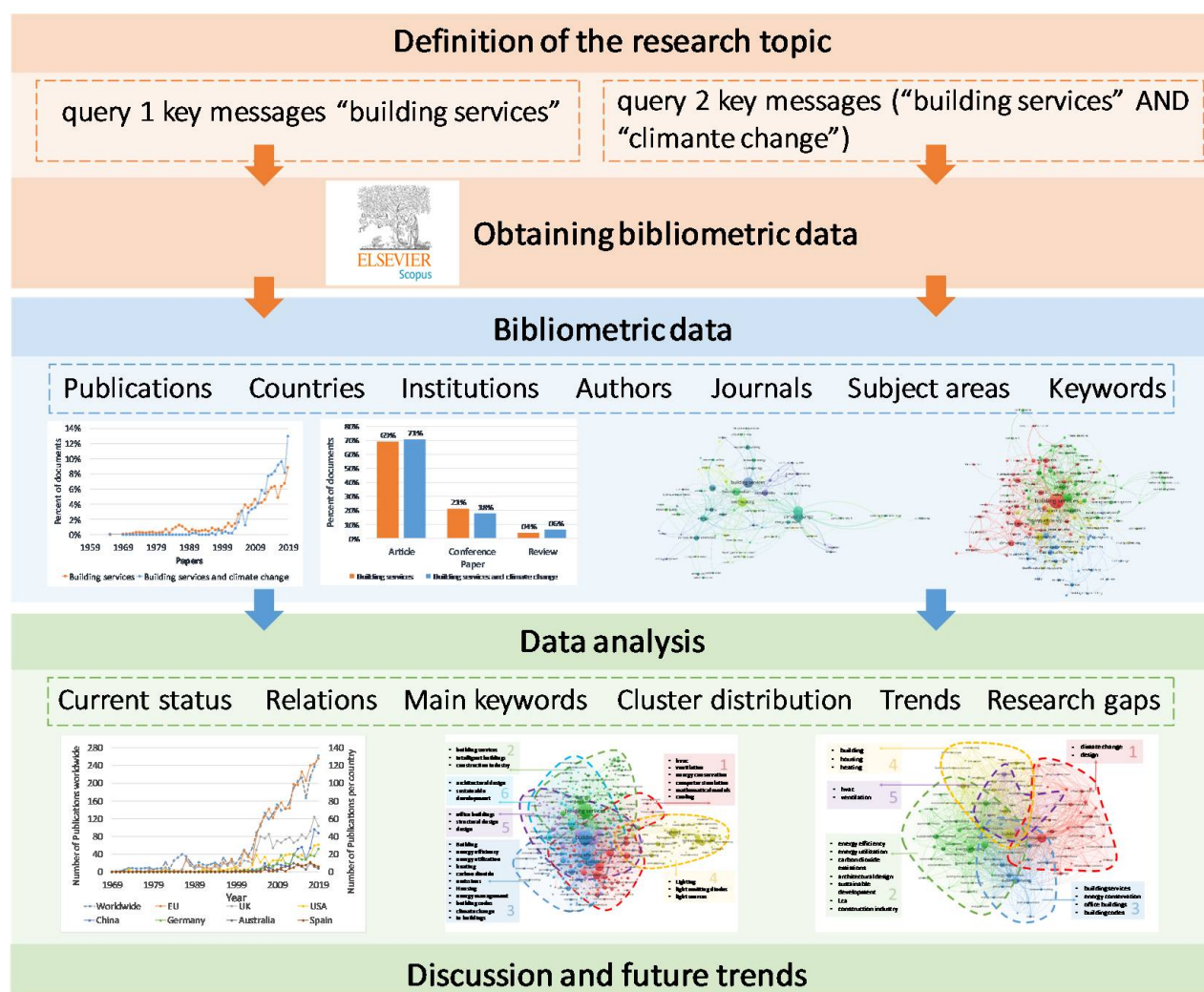


Figure 2. Methodology of the paper.

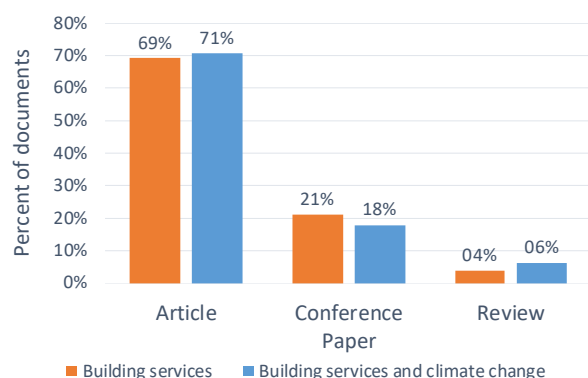
The world population was obtained from the United Nations, Department of Economic and Social Affairs [11], and the number of researchers from the United Nations Science Report [12].

3. Results

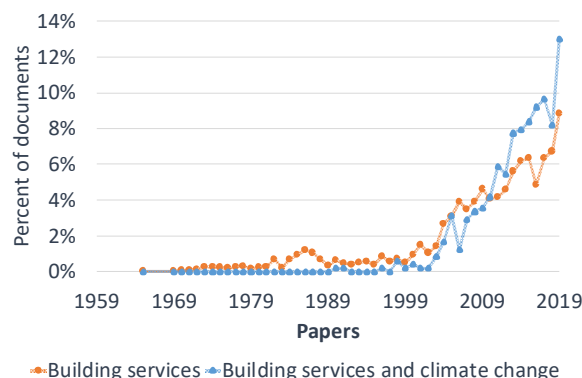
3.1. Bibliometric Analysis

The search carried out on 14 March 2020 revealed 3300 documents related to building services and 477 publications related to building services and climate change. Figure 3a shows that nearly 70% of those documents are papers/articles, and about 20% are conference papers; reviews, book chapters and other types of documents are anecdotic. Moreover, the statistics are similar for the two queries. The assessment of the trends in Figure 3b reveals that both queries have the same profile, with documents talking about the topic since 1965, but with a growth in interest in 2000–2002, and somehow a stagnation in 2014–2015. Considering the countries with more publications on the topic of study and with good representation of the different continents, Figure 3c shows that the EU publishes one-third of the literature published worldwide. The UK published a similar number of documents as the EU; although, in the last ten years, this number seemed to stagnate (in 2010, the UK had nearly the same number of publications as the EU—37 and 39, respectively, while in 2018, it had only half—62 and 122, respectively). China increased its publication rate on the topic only recently (in 2015, it published 28 documents and 48 in 2018). When the relation with climate change is considered (Figure 3d), the UK shows a higher number of

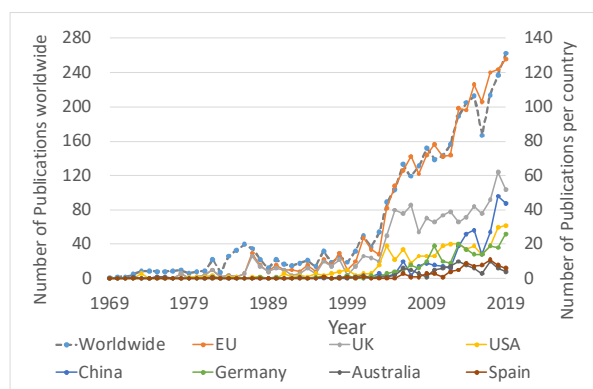
publications but also more stability than the other countries/territories considered. The EU has more publications than the UK, and all other countries have much fewer documents.



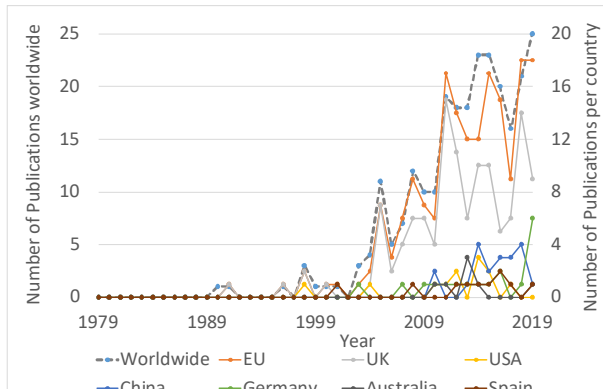
(a)



(b)



(c)



(d)

Figure 3. (a) Type of documents, (b) trends in publications, (c) trends in countries general query, and (d) trends in countries query with climate change.

Figure 4 shows the specific number of publications for the countries/territories with more documents. It is interesting to see that although the EU is the territory with more publications, its contribution only stands out when the number of documents per number of researchers with the general query is considered. The USA stands out when the number of publications per number of inhabitants is considered for both queries. China stands out when the number of publications per number of researchers in the query with climate change is considered, focusing their studies on LED light sources, as shown in Figure 4e, to improve energy efficiency [13–15], and 12 publications in the *Lighting Research and Technology* journal.

The relations between countries/territories are presented in Figure 5. In both queries, the EU centralize all collaborations, and in both queries, China and South Korea are the newest countries to appear (in the general query, Jordan also appears as new). It is interesting to see that the research on building services is older in the USA and Canada than in the EU, while its relation to climate change is older in the EU, which could be because of the fast implementation of climate change mitigation policies in the EU [16] (in general, this relation with climate change is newer).

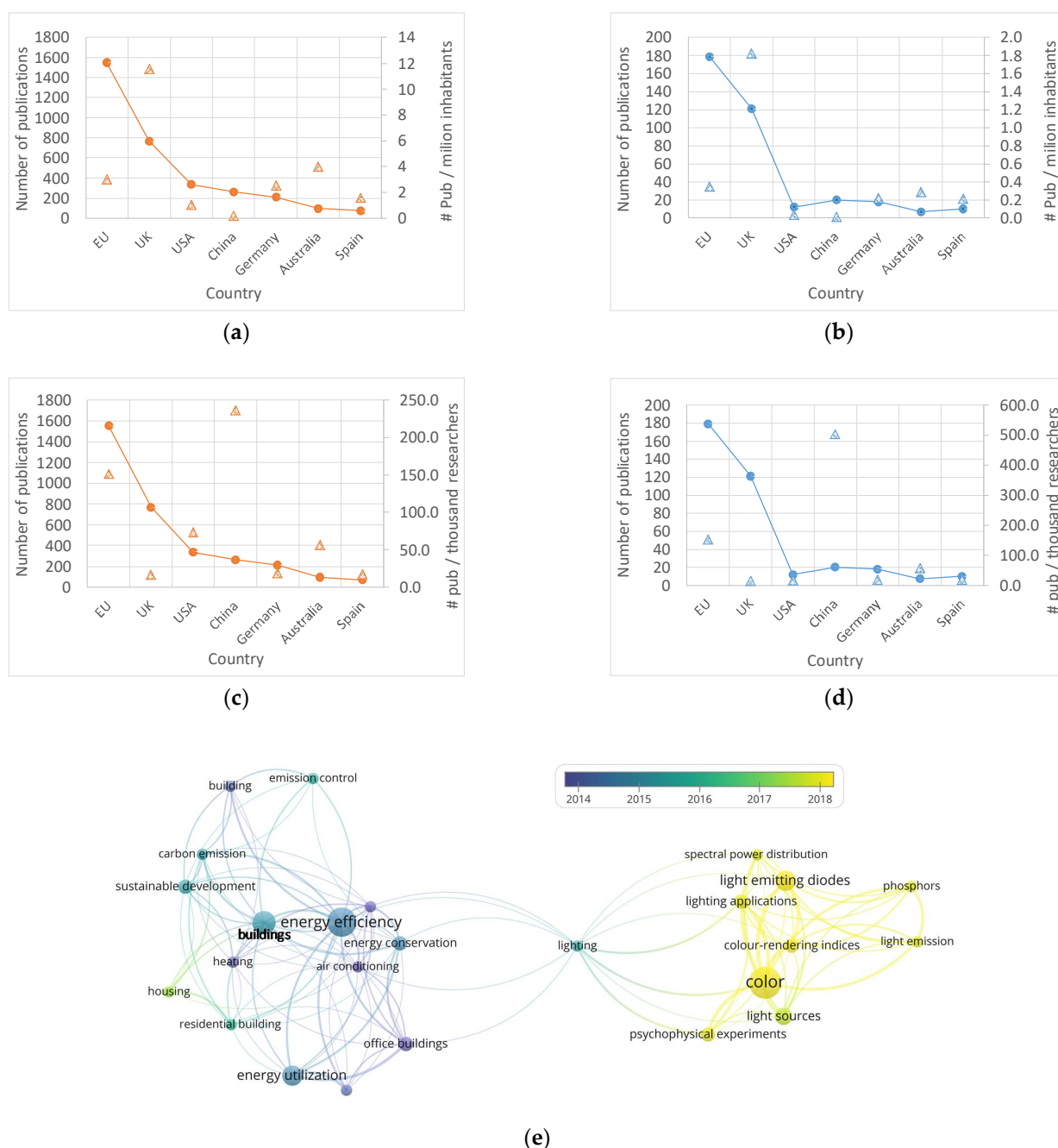


Figure 4. Scientific production per country: (a) per million inhabitants (general query), (b) per million inhabitants (query with climate change), (c) per thousand researchers (general query), (d) per thousand researchers (query with climate change), and (e) overlay visualization for China (query 2).

Table 1 lists the researchers with more documents on the topic of building services (Query 1). It is interesting to see that there is not a clear correlation between the authors with more publications and the countries with more publications. For example, the UK includes three authors (Steve A. Fotios, Michael J. Davis, and Chris Cheal), and only two institutions are represented (University of Sheffield with two authors and Univ. College London). Hong Kong also contributes with three researchers, but in this case, only one institution is represented (Hong Kong Polytechnic University). In both cases, we find two researchers publishing together, Steve A. Fotios and Chris Cheal for the UK, and L.T. Wong and K.W. Mui for Hong Kong.

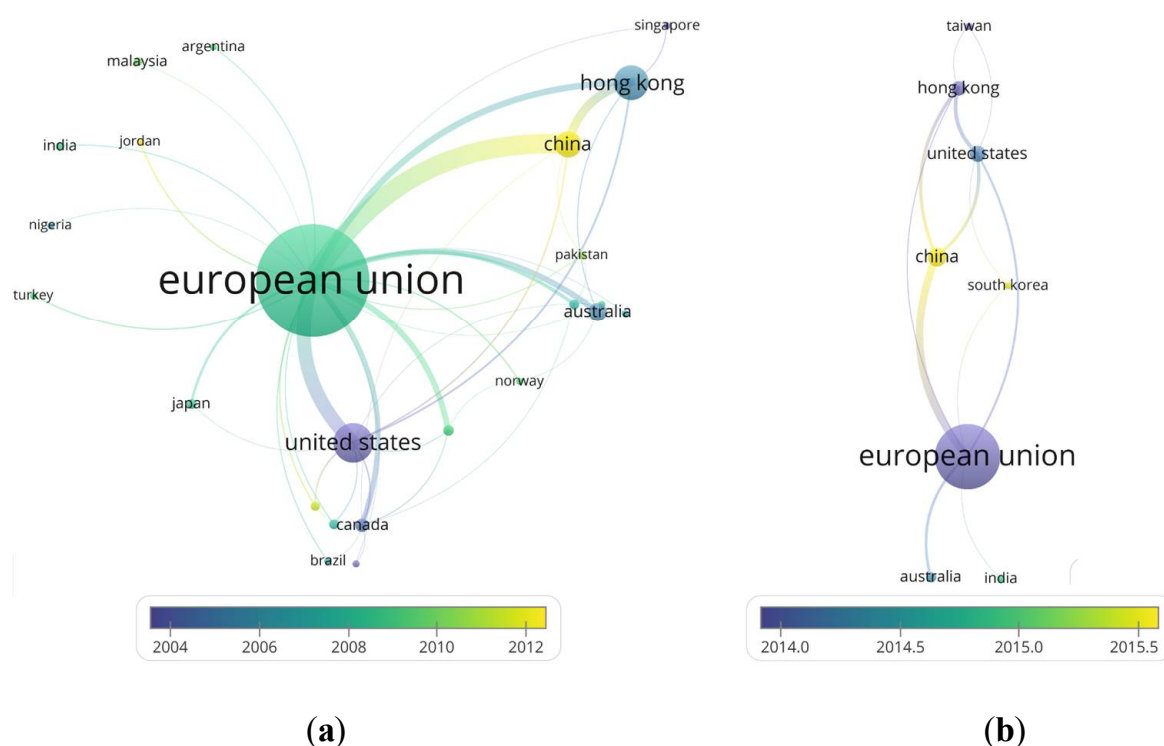


Figure 5. Relations between countries/territories: (a) general query, (b) query with climate change.

Table 1. Authors with more publications on the topic of building services and their impact.

Author	Institution	Country	#doc Search	h-Index Search	Total doc	Total h-Index
Steve A. Fotios	University of Sheffield	UK	39	13	120	20
Wim Zeiler	Technische Universiteit Eindhoven	Netherlands	32	4	171	15
Mark S. Rea	Rensselaer Polytechnic Institute	USA	29	15	220	41
L.T. Wong	Hong Kong Polytechnic University	Hong Kong	26	7	178	23
Michael J. Davis	University College London	UK	24	9	135	33
Liisa Halonen	Aalto University	Finland	24	11	75	18
Kowk Wai Mui	Hong Kong Polytechnic University	Hong Kong	24	7	142	22
Ming Ronnier Luo	State Key Laboratory of Modern Optical Instrumentation	China	23	8	129	16
Chris Cheal	University of Sheffield	UK	22	12	41	14
Cheuk Ming Mak	Hong Kong Polytechnic University	Hong Kong	21	8	203	24

Furthermore, the topics of research are different for the different authors and countries/territories. For example, the main topic of S.A. Fotios from the UK and M.S. Rea from the USA is lighting [17–22]. W. Zeiler from the Netherlands studied building design from the human perspective point of view [23], and energy efficiency [24]. L.T. from Hong Kong worked on indoor air quality, pollution, and ventilation [13].

Finally, Table 1 shows that all these authors study topics related to building services but without this being their unique research interest.

As expected, the journal *Building Services Engineering Research and Technology* is one of the journals with more documents (511) (Figure 6a), but surprisingly, the journal *Lighting Research and Technology* has more publications (670). All other journals used have much fewer

documents on the topic, i.e., the third journal is *Energy and Buildings*, with 55 documents. On the other hand, when the relation with climate change is studied (Figure 6b), the journal *Building Services Engineering Research and Technology* includes 88 documents, more than four times the second journal listed.



(a)



(b)

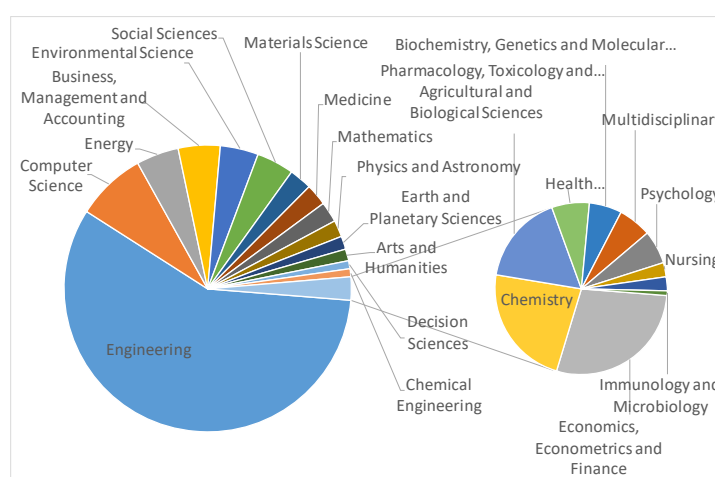
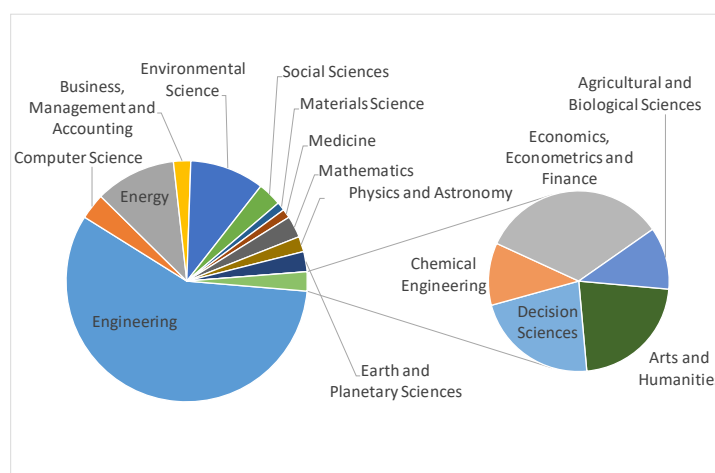
Figure 6. Journals used to publish this research topic: (a) general query, (b) query with climate change.

Table 2 shows that when the authors select the journal to publish their research on the topic, the impact factor and classification of the journal is not as important as the scope of the journal (the first and second journal are Q2 and Q3, respectively). This is interesting to highlight since this is not the same trend found in other studies on different topics [8].

Table 2. Journals with more publications on the topic of building services and their impact.

Journal	#pub	Editorial	Impact factor (2018)	Classification (2018)	Open Access
Lighting Research and Technology	670	SAGE Journals	2.311	Q2	No
Building Services Engineering Research and Technology	558	SAGE Journals	1.170	Q3	No
Energy and Buildings	55	Elsevier	4.495	Q1	No
Facilities	33	Emerald Group Publishing Ltd.	—	—	Yes
Building and Environment	23	Elsevier	4.820	Q1	No

Finally, Figure 7 shows that most documents published on the topic of building services are within the area of engineering (77% in building services and 78% in building services and climate change). All other areas found have a much lower number of publications (i.e., computer science includes 9% of documents on building services). However, it is interesting to highlight that in building services, the next most published topics are climate change energy 15% and environmental science 13 %.

**(a)****(b)****Figure 7.** Subjects used to publish this research topic: (a) general query, (b) query with climate change.

3.2. Keywords Network Analysis

Table 3 and the literature map presented in Figure 8 (the one for the general query) shows that the co-occurrences keywords can be grouped into six clusters. The first one, in red, groups “hvac” and “ventilation” with the building service “thermal comfort”. Interestingly, “thermal comfort” is also linked to “air quality” and “indoor air pollution”, as is stated in [25,26]. This cluster also groups “hvac”, with “energy conservation”, “computer simulation”, “mathematical model”, “optimization”, and “control” [27–31], and “elevator”, with “Monte Carlo method” and “high rise building”. The second cluster, in green, links “building services” with “intelligent buildings” (also related to control in cluster 1), “bems”, and “control system”. It also groups “building service” with “construction industry”, and “project management”, “maintenance”, and “cost”. The third cluster, in blue, groups “building”, “energy efficiency” and “energy utilization” with “building codes”, “climate change”, “carbon dioxide emissions”, and “renewable energies”. It is important to highlight the keyword “energy efficiency” in this cluster as it has the highest number of occurrences (324) of the map (excluding the keywords present in query 1), therefore is of great interest in the research on building services [32–37]. The fourth cluster, in yellow, groups the “lighting” building service; this keyword has been of great interest globally since the introduction of light-emitting diodes (LED) and their low energy consumption as reflected in [37–41], thus the strong relationship with “energy efficiency” is expected. This cluster groups “lighting”, “engineering research” and “light emitting diodes”, with “light sources”, “color”, “luminance”, “spectral power distribution”, and “color rendering”. The fifth cluster, in purple groups “office buildings”, “structural design”, and “design”, with “lca”, “environmental impact” and “building material”. The last and sixth cluster, in light blue groups “architectural design” and “sustainable development” with “sustainable building” and “built environment”.

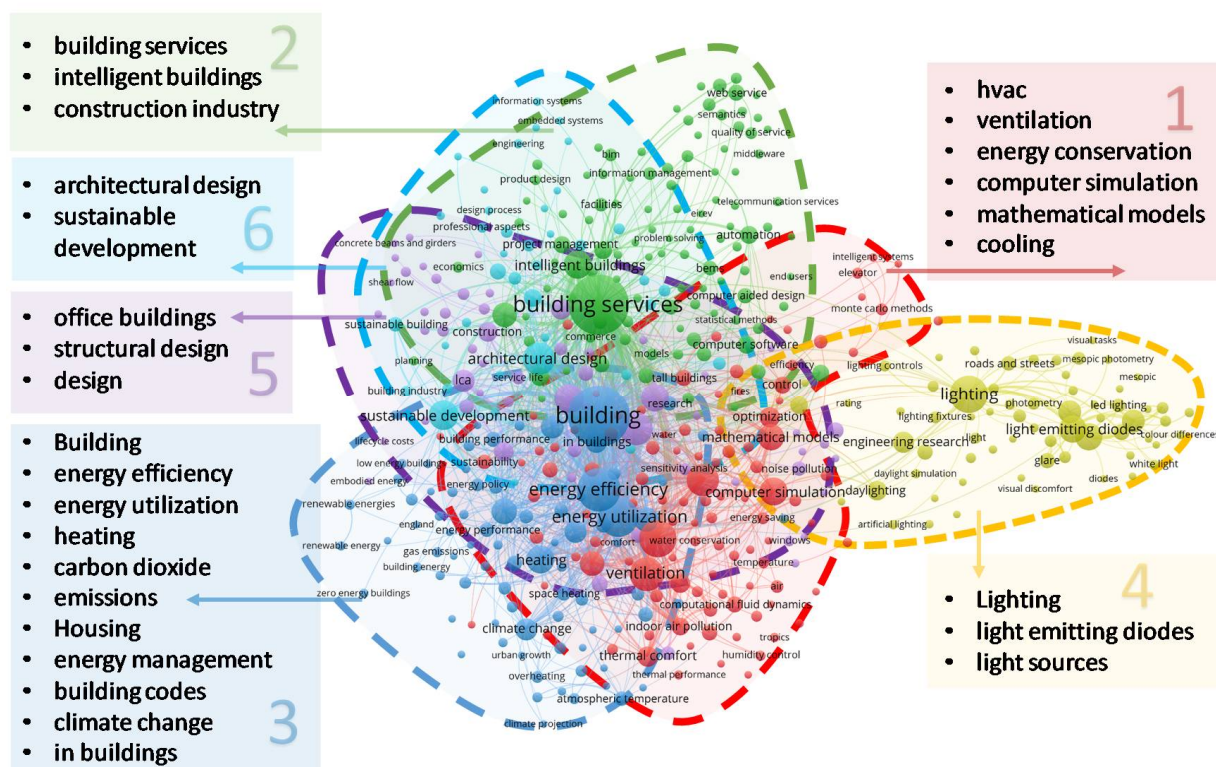


Figure 8. Co-occurrence keywords network query 1.

Table 3. Keywords with more than 80 occurrences (query 1).

Cluster	Label	Occurrences	Avg. Pub. Year	Avg. Citations
1	hvac	248	2008	10.85
	ventilation	200	2008	10.79
	energy conservation	178	2010	11.19
	computer simulation	140	2006	23.29
	mathematical models	123	2004	16.63
2	cooling	108	2011	12.77
	building services	621	2009	11.89
	intelligent buildings	135	2012	9.78
	construction industry	110	2008	8.14
3	building	666	2005	16.54
	energy efficiency	324	2013	25.08
	energy utilization	273	2012	27.60
	heating	136	2009	12.31
	carbon dioxide emissions	111	2013	15.67
	housing	108	2014	11.43
	energy management	96	2009	12.29
	building codes	87	2008	10.37
	climate change	87	2012	25.41
	in buildings	80	2011	5.33
	lighting	256	2013	15.37
4	light emitting diodes	129	2016	9.04
	light sources	127	2014	14.00
	color	94	2016	12.07
	luminance	92	2014	13.78
	engineering research	80	2014	8.95
5	office buildings	192	2012	12.52
	structural design	151	2008	8.89
	design	136	2012	8.03
	lca	89	2013	11.21
6	architectural design	185	2013	9.60
	sustainable development	152	2012	10.46

When “climate change” is added to the query, a more detailed analysis can be done, as shown in Figure 9 and Table 4. The first cluster, in red, groups “climate change” and “design” with “building simulation”, “energy use”, “weather data”, “meteorology”, and “urban heat island”. This cluster shows the effort made to achieve mathematical models that represent complex phenomena such as urban heat island [42,43], which in building services is highly necessary for efficient energy retrofit of existing buildings [44] and is used to optimize the dimensioning of heating and cooling systems [45]. The second cluster, in green, groups “energy efficiency”, “energy utilization”, “carbon dioxide emissions” and “architectural design”, with “environmental impact”, “embodied energy”, “lca” [46,47], “sustainable development”, and “intelligent building”. Interestingly, “energy efficiency” continues to have the highest number of occurrences (61) of the map (excluding the keywords present in query 2). The third cluster, in blue, links “building services”, “energy conservation”, and “office buildings”, with “building codes”, “climate control”, and “lighting”. The use of the Passivhaus [48] and NZEB standards [49] have proved to be effective in improving the building’s energy efficiency, but it has also increased the overheating risk [50–52]. Therefore, the fourth cluster, in yellow, groups “building”, “energy management”, and “heating” with “thermal comfort”, “building performance”, and “overheating”. This cluster also links “building” with “housing” and “retrofitting”. The fifth and last cluster, in purple, links “hvac” with “ventilation”, “air quality”, and “natural ventilation”.

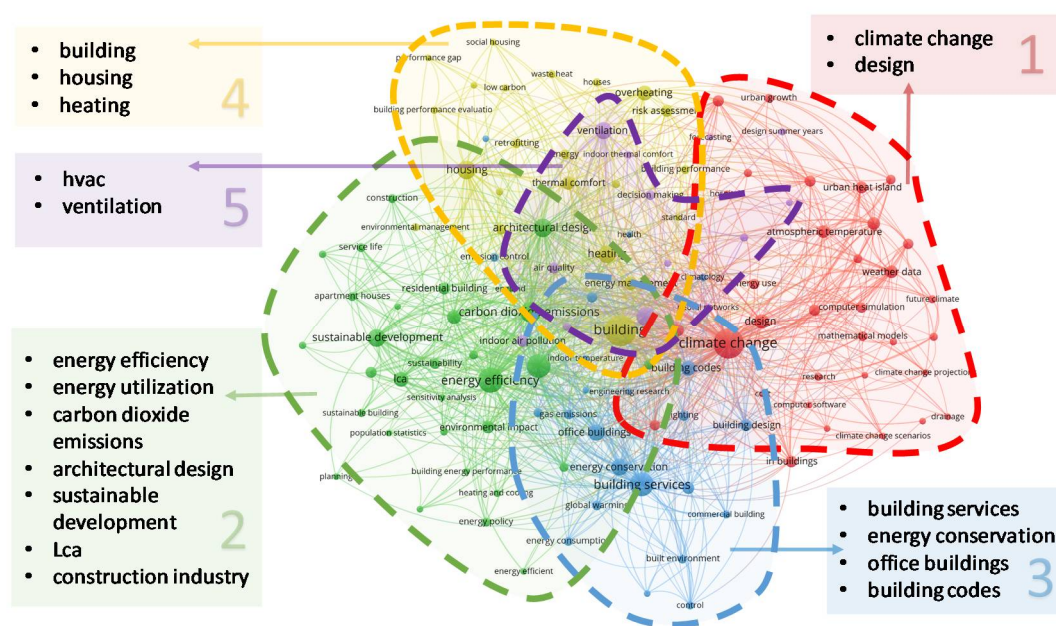


Figure 9. Keywords network (query 2).

Table 4. Keywords with more than 20 occurrences (query 2).

Cluster	Label	Occurrences	Avg. Pub. Year	Avg. Citations
1	climate change	87	2012	25.41
	design	22	2012	12.86
2	energy efficiency	61	2014	74.25
	energy utilization	55	2014	72.11
	carbon dioxide emissions	42	2015	26.00
	architectural design	34	2015	7.62
	sustainable development	31	2013	16.13
	lca	22	2015	11.23
	construction industry	20	2014	10.30
3	building services	52	2013	75.69
	energy conservation	29	2014	21.14
	office buildings	25	2013	13.84
	building codes	21	2013	22.43
4	building	97	2013	57.79
	housing	32	2016	12.00
	heating	30	2014	19.33
	overheating	22	2017	9.50
5	hvac	35	2013	14.83
	ventilation	29	2015	17.69

4. Discussion, Past Trends and Future Perspectives

To better understand which building services are analyzed in the literature with more emphasis on climate change, Figure 10 shows the keywords that have a direct link with “building services” and “climate change” keywords in query 2. It shows that “energy efficiency” is one of the most studied topics with the highest number of occurrences (440) and the highest link strength with both “building services” (16) and “climate change” (20). The next keywords are “energy utilization” and “hvac”. Moreover, “ventilation”, “heating” and “climate models” have a clear affinity to climate change, while “sustainable development” and “lca” have higher affinity to “building services”.

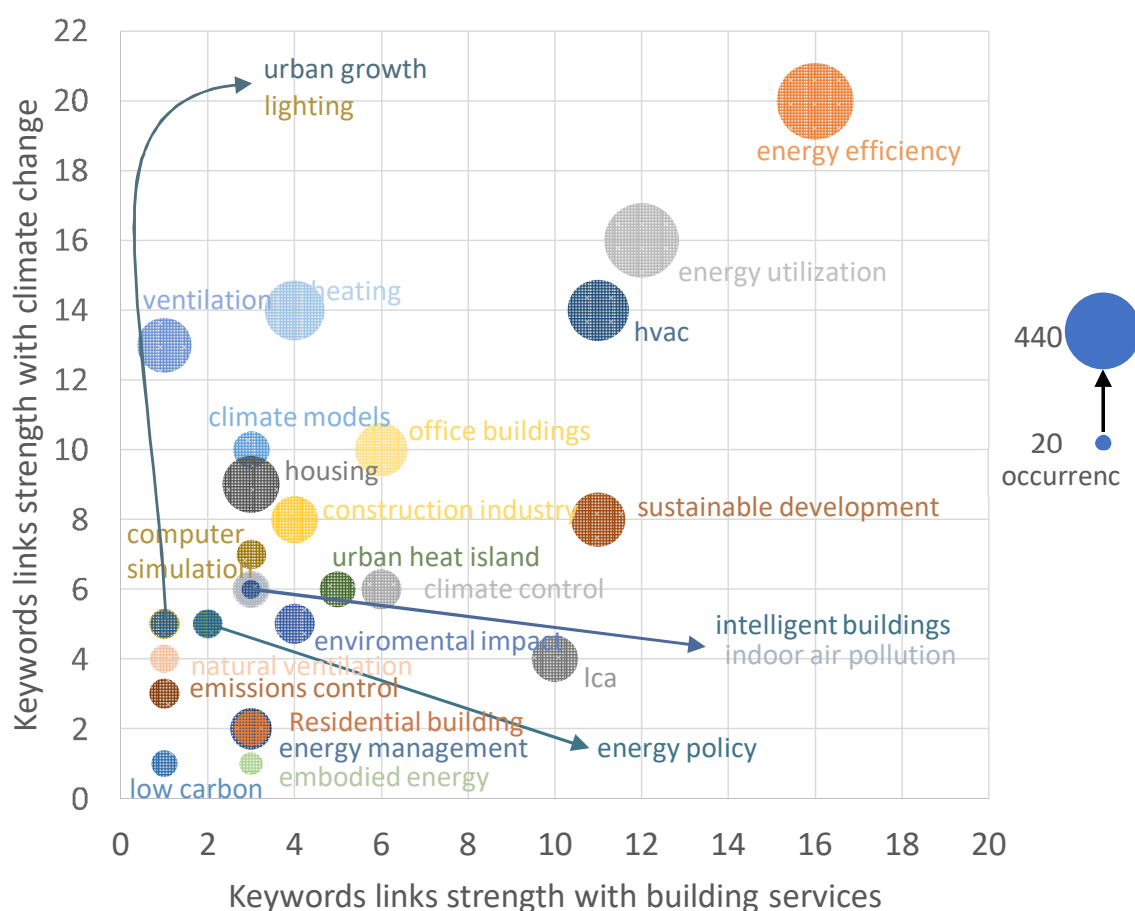
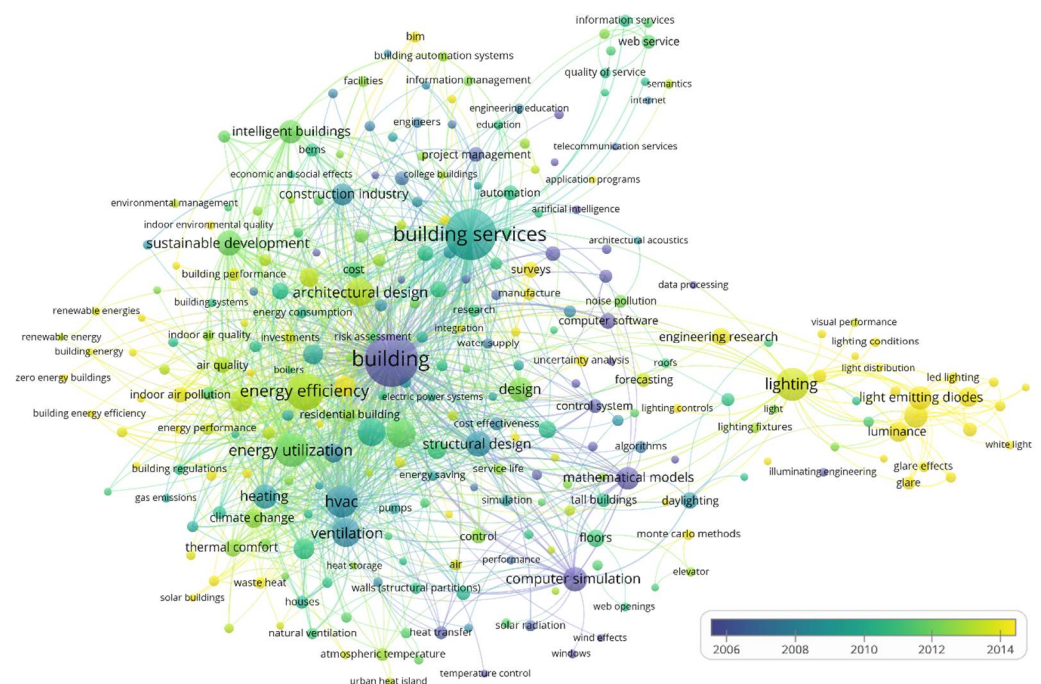


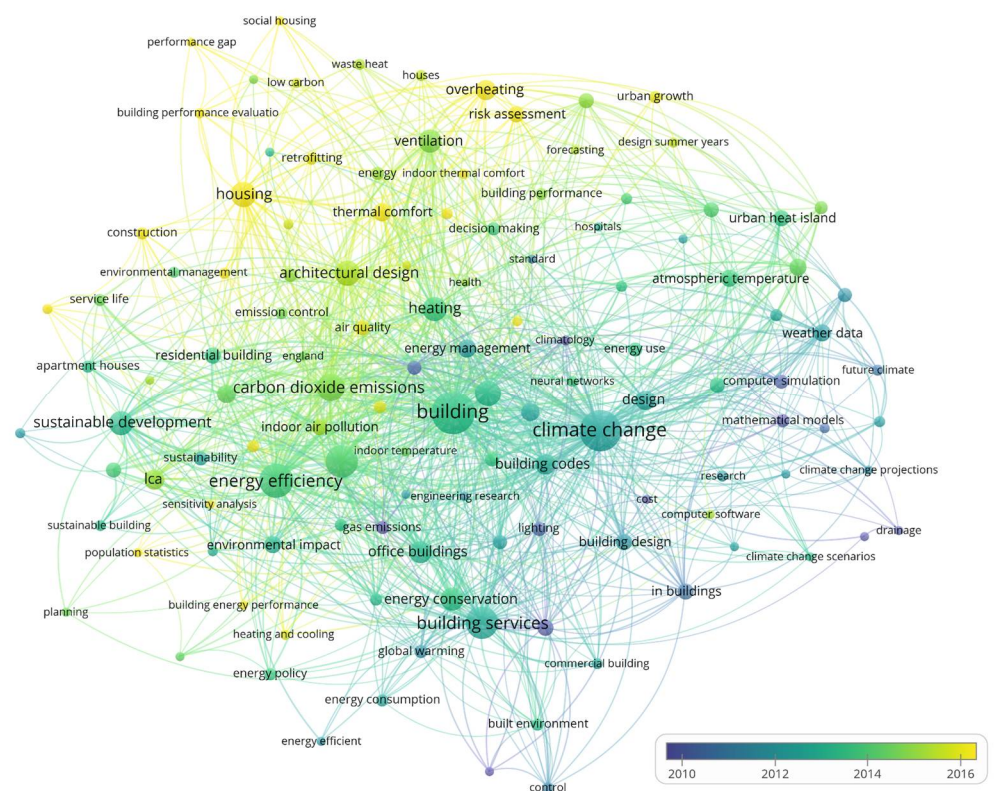
Figure 10. Keywords link strength directly related to building services and climate change in query 2 keywords network analysis.

Following the trend presented in Figure 3b, the overlay visualization by year of the keyword analyses (Figure 11) shows that most keywords appear after 2002, highlighting the progress of research towards new topics. Figure 11a shows that the keywords used in earlier documents were “maintenance”, “architecture”, “project management”, also “computer simulation” and “mathematical models”, related to “control system”, “hvac”, “ventilation”, and “heating”; indeed, these are the building services classified within the safety and comfort types in Figure 1. However, most recent interests have changed to energy efficiency topics such as “lighting”, “luminance” and “led emitting diode”, the transition from building to city with “urban heat island”, and more recent building subjects such as “embodied carbon”, “data centre”, “overheating”, “performance gap”, and finally “bim”, which are within the efficiency and climate change types in Figure 1.

Moreover, when the relation between building service and climate change is studied Figure 11b, with all the topics newer than in query 1, the keywords used in earlier documents were “gas emissions”, “climate control” and “building regulations” [53], showing that the literature related building services with climate change when HVAC systems are studied, also mentioning regulations and policies. Recent interests can be grouped, for example, social topics like “housing” close to “social housing”, “urban growth” and “retrofitting” [46,54,55], highlighting that retrofitting of social housing is a topic to consider to ensure thermal comfort to low-income population and to avoid energy poverty. Other recent keywords are “overheating”, “risk assessment”, “thermal comfort”, and “embodied energy”, with the latter closely related to “carbon dioxide emissions”, “energy efficiency”, and “lca” [56,57], showing the growing importance of sustainable topics in recent research.



(a)



(b)

Figure 11. Trends in keywords network: (a) general query, (b) query with climate change.

5. Conclusions

This paper presents a bibliometric-driven analysis of research trends in the field of building services and their relationship to climate change. It was developed using data from

the Scopus database from 1969 to March 2020. Two queries were analyzed, TITLE-ABS-KEY (“building service*”) and TITLE-ABS-KEY (“building service*” AND “climate change”). The results of both queries were analyzed in terms of publications by years, countries and top journals in which the research was published and through a keyword network analysis. This made it possible to identify the most recent research trends. The most recent research on building services can be associated with safety, comfort and efficiency. The studies show that improvements in thermal efficiency in buildings and improvements in air quality are made by studying natural ventilation techniques coupled with HVAC systems and the development of new HVAC technologies. On the other hand, improvements in electrical efficiency focus on the use of LED lighting and the use of intelligent control strategies, optimized through building simulations. When relating building services to climate change, the most recent studies focus on social aspects such as social housing, urban growth, and thermal comfort. The main research gaps identified are the lack of integration of the four groups of building services identified in this study in order to draw more effective research in the fight against climate change. Finally, the study of building services not related to energy services is also a research gap.

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